Best Use of a Digital Piano:

Focus on Sound and Key Action

— Brief Report —

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Introduction

Although Roberto owns and primarily uses a decent grand piano, he also needs to use a digital piano to practice silently in consideration of his family. While this arrangement works well, he wants to make sure that the skills acquired on the digital piano transfer to those on the grand piano.

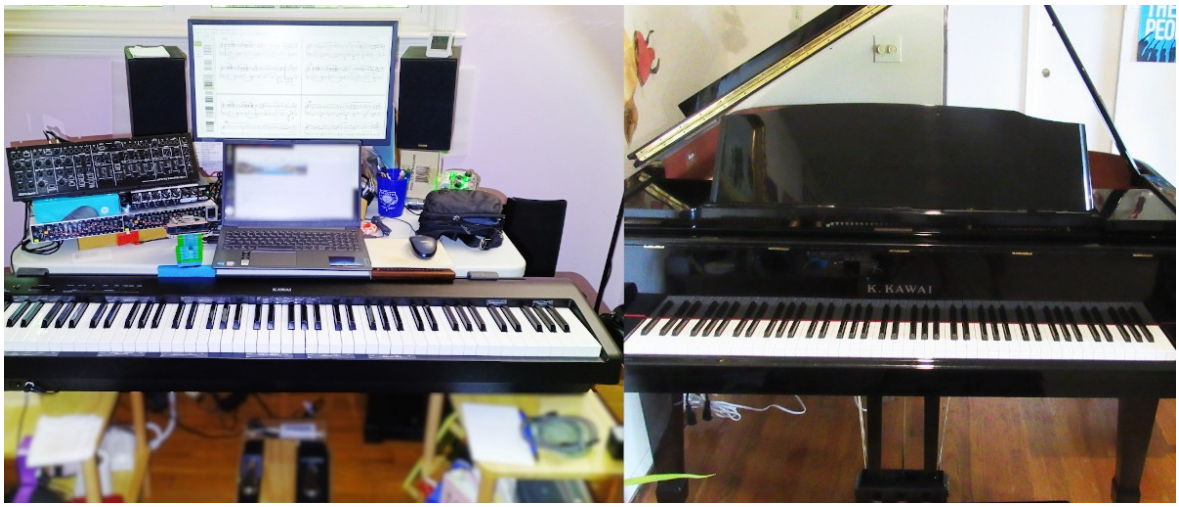
In addition, facing the possibility of downsizing to an apartment, Roberto is thinking about replacing his aging digital piano with a new/better one, which would be his only "piano" in the new apartment setting. For this option, Roberto considers only *portable* digital pianos because those can fit compactly within his work area (image at the end of this section).

So, from both of these perspectives, Roberto has been looking into various properties of a digital piano very carefully. In this report, we look at Roberto's observation, focusing on sound and key action. In particular, he focuses on (1) how to make a digital piano sound (from external speakers) as close as possible to a grand piano and (2) four areas where he investigates the properties of digital piano key action as well as how to test them.

Unlike usual discussions of digital pianos, Roberto pays little attention to most other features of digital pianos, including the quality of built-in speakers (if any), the number of available sounds, connectivity, ability to record, availability of lessons, etc. Those are irrelevant to him.

This report is in a sense an update to the two previous documents about Roberto's experience (Between Acoustic and Digital Pianos: Sound and Key Touch (Static Touchweight, Escapement/Let Off, Inertia) - Case Study and Digital Piano Key Action Diagnostic Properties - Report). However, it is actually intended as a self-contained document, hopefully more streamlined than the predecessors.

Disclaimer: This document describes the experience of Roberto, an untrained piano hobbyist. So, the information in this document must be regarded as such. Note that Roberto's digital piano is Kawai ES100 (2016, newer models appeared since then) and his grand piano, Kawai GS-30 (ca. 1982), as shown in the following image.



Sound

The sound of digital pianos have improved tremendously over the last several decades. So, at least initially, Roberto was not very concerned about this aspect. Any modern digital piano should be as good as he hopes. However, as he continues to explore this topic, he started to notice areas for further discussion.

Headphones

First, Roberto uses his digital piano usually with headphones for silent practice. In fact, this would be the most straightforward and simplest way to enjoy the sound of a digital piano, eliminating a lot of interfering factors between the sound source and the player's ears.

As for his headphone choice, Roberto followed the suggestion on a web site called "Audio Check" (https://www.audiocheck.net/) and purchased Superlux HD668B. He is quite satisfied with the product in terms of the quality and also the price. He can use the headphones comfortably for a long time and enjoy the sound of his digital piano very much.

Still, Roberto was curious about the frequency response of the headphones. For this purpose, he used the audio sweep sound available on Audio Check. The frequency response appeared fairly flat overall. Online product reviews too are in general very positive, except that some reviewers point out that treble is slightly more pronounced (e.g., https://www.rtings.com/headphones/reviews/superlux/hd-668b).

As part of his search for the next digital piano, Roberto visited many piano stores and tested many digital pianos from different manufacturers. To find out if he likes a particular model, he played for fairly long time on each model, using his headphones. To his surprise, there were models which he started to feel uncomfortable hearing the sound of. That is, his extensive headphone tests revealed certain characteristics of those models, which Roberto did not like.

So, Roberto felt that there are digital pianos he should avoid, just based on their sounds. Since sound preference is subjective, a potential buyers of a digital piano needs to find out for themselves.

External Speakers

Even though Roberto primarily uses headphones with his digital piano, Roberto still wants to hear good piano sound from speakers. However, the internal speakers of his digital piano are utterly inadequate. In fact, no internal speakers of a portable digital piano would satisfy Roberto. As for console and hybrid pianos (although Roberto would not consider any of these), Roberto's hunch is that he would be satisfied only by high-end products with very good speakers.

As shown in the earlier image of his work area, Roberto has a laptop computer (often used for listening to music). Since the internal speakers of his computer is totally inadequate for this purpose, Roberto feeds the output of the computer to an audio system.

Long time ago, Roberto bought and used an inexpensive "computer" audio system. However, he realized that this type of audio systems would not satisfy his taste. So, his current setup consists of slightly better audio products: Fosi Audio power amp (TDA7498E), Klipsch speakers (R-14M), and Yamaha subwoofer (YST-SW215).

Then, Roberto's obvious choice is to use his audio system for both his computer and digital piano. He uses a nice compact mixer (Rolls Minimix PRO MX122) to combine multiple inputs. In order to simulate the position of a grand piano's soundboard, he placed the speakers slightly in back on the work table (as in the earlier image).

Although the Fosi amp is advertised as 160 watts per channel, Roberto does not think it is actually capable of producing that much, especially with the relatively small power adapter that came with the amp. Nevertheless, it is more than enough for his needs. This configuration was sufficient to make the sound of his digital piano even louder than that of his grand piano. Looking at the spec of various digital pianos, Roberto thinks that the power needed to produce sounds as loud as an acoustic piano would be at least 20~40 watts per channel.

The frequency range of his Klipsch speakers can go down to about 60Hz. Thus, they can cover the fundamental frequencies of all the piano notes except for the lowest octave. Compared to the internal speakers, these speakers alone can produce much deeper bass sound. Then, the missing range can be supplemented by the Yamaha subwoofer. However, in order not to exaggerate the bass sound, Roberto adjusted the cutoff frequency of the subwoofer fairly low. Now, Roberto's audio system can produce the complete frequency range of the piano sound. The outcome is obvious. The sound is far louder, richer, and more realistic than that from his digital piano's internal speakers.

However, this still did not satisfy Roberto. He thought that the sound, especially the mid-range, is muffled. He also read a number of comments about muffled digital piano sound. Roberto thought one of the main factor is room acoustic. This is because not only the sound of his digital piano but also the sound of Musescore grand piano was similarly muffled.

However, room acoustic is notoriously challenging to address. Roberto doesn't even think about designing and implementing an acoustically perfect room. So, his solution was to use graphic equalizer (Behringer FBQ1502HD, shown below) to adjust the frequency response.

This is a reasonable solution for Roberto. Adjustment is doable and easily adjustable to any new environment, for example, even after moving to an apartment. Roberto started with try-and-error approach to adjust the level of each band of the equalizer. Then, he gradually adopted a semi-systematic approach.

Roberto created a Musescore file to play all the C, E, and G notes available for pianos (88 keys). Then, he selected one or two octaves (at a time) and played the notes repeatedly at a desirable tempo. During the repetition, he switched between headphones and speakers.

Roberto can now compare the sounds by gradually adjusting relevant bands of the equalizer so that the tonal quality of brightness/mellowness for each note becomes similar between from the headphones and from the speakers. He realized that the key to decrease the "muffledness" from the mid-range notes (in his environment) was to implement upward slope of equalizer setting from around 250Hz to around 1.5kHz of about 10dB difference total in this range (shown in the above image). Other areas were not as critical. As for the bass setting, it needs to be adjusted in accordance to the subwoofer setting.

In order to check the frequency response, one might think of using the audio sweep. However, this does not seem very realistic. Unlike headphones test (for which the audio sweep is created), the flatness check of speaker sounds appears to be trickier. Roberto thought that the use of piano sound tonality is much more practical.

After the adjustment of the equalizer, Roberto is finally satisfied with the sound of his digital piano from the external speakers. He thinks that his setup can match the sound quality of high-end digital/hybrid pianos. Although Roberto's digital piano (old model) comes only with Kawai's EX sound (not the latest SK-EX sound), he has no complaints.

Listening to Music

After adjusting the equalizer for the digital piano, Roberto realized that the new setting is also good for listening to music from the computer. Before doing this, he never thought about his audio system's uneven frequency response. That is partly because it is not so easy to analyze the frequency response just by listening to music. Roberto thought that adjusting the equalizer by using the tonal quality of a digital piano is much more practical.

Now, Roberto likes the new sound setting much more. For example, the vocal part of his favorite music sounds as if the singer was right there. In addition, each instrument of the accompanying ensemble strikes out and becomes more distinguishable. If he bypasses the equalizer, the vocal part sounds as if the singer was behind a curtain. This must be related to the muffled digital piano sound.

So, the moral here is as follows. It would be a good practice to adjust the equalizer level for a particular environment by comparing the piano sound for each note from headphones and external speakers. This can improve the quality of the sound system. Of course, the quality of headphones must be decent.

Key Touch Overview

In terms of both skill transfer (from a digital to a grand piano) and new digital piano selection, Roberto pays a special attention to key touch. It is fairly obvious to Roberto that the key touch is very different between digital and grand pianos. However, it was not at all easy to pinpoint the involved properties. So, he did a lot of experiments.

After some time, Roberto came up with four areas of discussion. For each area, he identified a relevant property and also a test method to measure the property. His experience is summarized in the following table.

#	Starting Points	Property	Test
1	Key Back Playability, Static Touchweight	Touchpoint Difference	Slope Test
2	Soft Touch, Escapement Mechanism	Direct Action Engagement Timing	Limiting Test
3	Repetition, Fast Movement	Inertia (resistance to change)	Tapping Test
4	Fatigue	Friction (resistance from rubbing)	Pen Test

#1: Touchpoint Difference

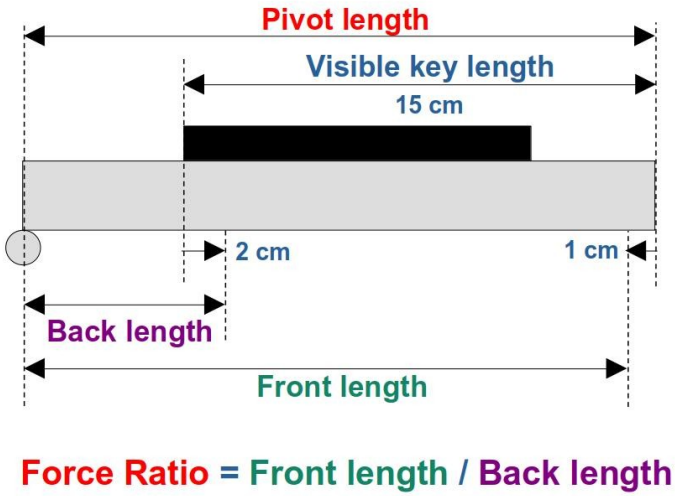
One of the musical pieces Roberto regularly practices is in D♭ Major. As such, he needs to depress a lot of black keys, especially the back of keys. When he was using his first digital piano, he had difficulty depressing the back of keys. This was because keys were much heavier at back. This condition made it extremely difficult for him to to play as he wished, especially softly. Eventually, Roberto replaced his first digital piano with the current one. This one does not have the same problem.

So, Roberto was naturally interested in key touch weight. In fact, the most-often-discussed property of digital piano key action is a kind of key weight, called static touchweight. This is a measurement of how much weight is needed for a key to go down. It is measured at the front of a key, usually with gram weights. Note that there are different types of touchweight, but we are not concerned about the differences here.

Roberto measured static touchweight on his grand and digital pianos. Both of them have about the same value of approximately 70 grams. This is also comparable to most other pianos. But there was a surprise. On his grand piano, the touchweight is about 35% lighter when the damper pedal is depressed. That is, part of the force is used to raise the damper. He never noticed the difference. On his digital piano, black keys are lighter than white keys by about 18%. He didn't notice this either. It seems that this much of difference in static touchweight does not have a clearly noticeable impact. So, this property *alone* should not be as important. Most popular digital pianos have decent static touchweight at least at the front of a key. So, if a review of digital pianos solely focus on this property, it would be shortsighted.

Nevertheless, as Roberto needed to replace his first digital piano, the static touchweight at the back of keys must be more relevant. So, instead of the static touchweight just at front, the difference between the front and the back must be more relevant.

The static touchweight difference between the front and the back of a key is called ***touchpoint difference***. This property is fairly straightforward to check by casually comparing the touchweight at the front and the back of a key (practically any key, for that matter). Then, Roberto learned that touchpoint difference is usually measured as the force ratio (i.e. the touchweight ratio between the front and the back) and is directly proportional to the pivot length (from the front of a key to where the key is pivoted). This can be seen in the following image.



As for most grand pianos, the pivot length is fairly long and the force ratio is about two (2). That is, even on grand pianos, the back of a key is about twice as heavy as the front. But this is actually the best case and players do not make a fuss. The force ratio

of a typical digital piano can be between two (best) to four (or even more). For example, imagine a digital piano with the front touchweight of about 100 grams and the force ratio of about 3.5. Then, the back touchweight would be about 350 grams! This appears huge and must be much more significant than 35% difference in static touchweight. Roberto's first digital piano was in this category.

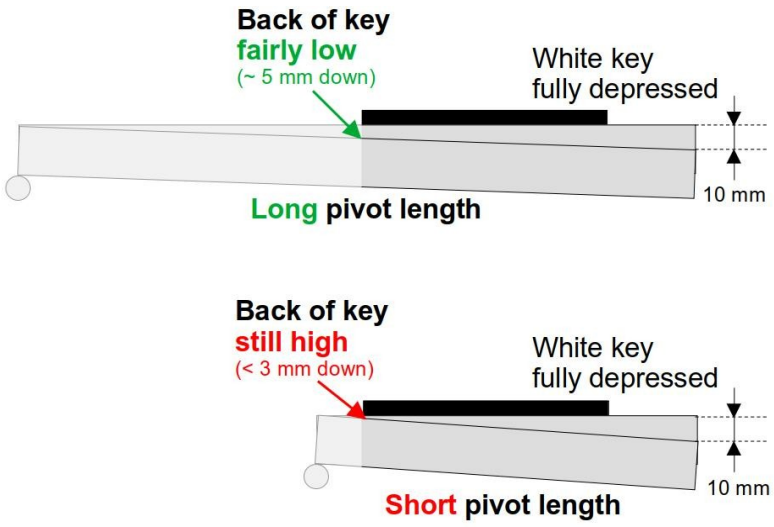
In addition to feeling the difference, there is a quick and easy way to quantify touchpoint difference. We just examine the slope of a fully-depressed key as described below.

Slope Test (Key Slope Test)

When a key (any white key for this test) is depressed, how much the back of the key goes down is proportional to the pivot length. So, the amount of key drop at the back end can be used to easily quantify the touchpoint difference.

On Roberto's grand piano, the result of the Slope Test is about 5 mm. His digital piano has a value of 4 ~ 5 mm, which is very good. If this amount is less than 3 mm, the digital piano may have a poor touchpoint difference. If less than 2mm, the touchpoint difference must be unmistakably poor. In comparison, Roberto also tried this test on his portable keyboard (often with fewer than 88 "springy" keys). The back of keys barely dropped; the force ratio must be enormous.

Now, a few millimeters of difference may seem a very small amount. However, that must be considered in the context of about 10 mm of key travel at front. Thus, even a small amount of difference in the key drop in the back may actually be reflected in a noticeable slope difference. The situation is represented in the following image.



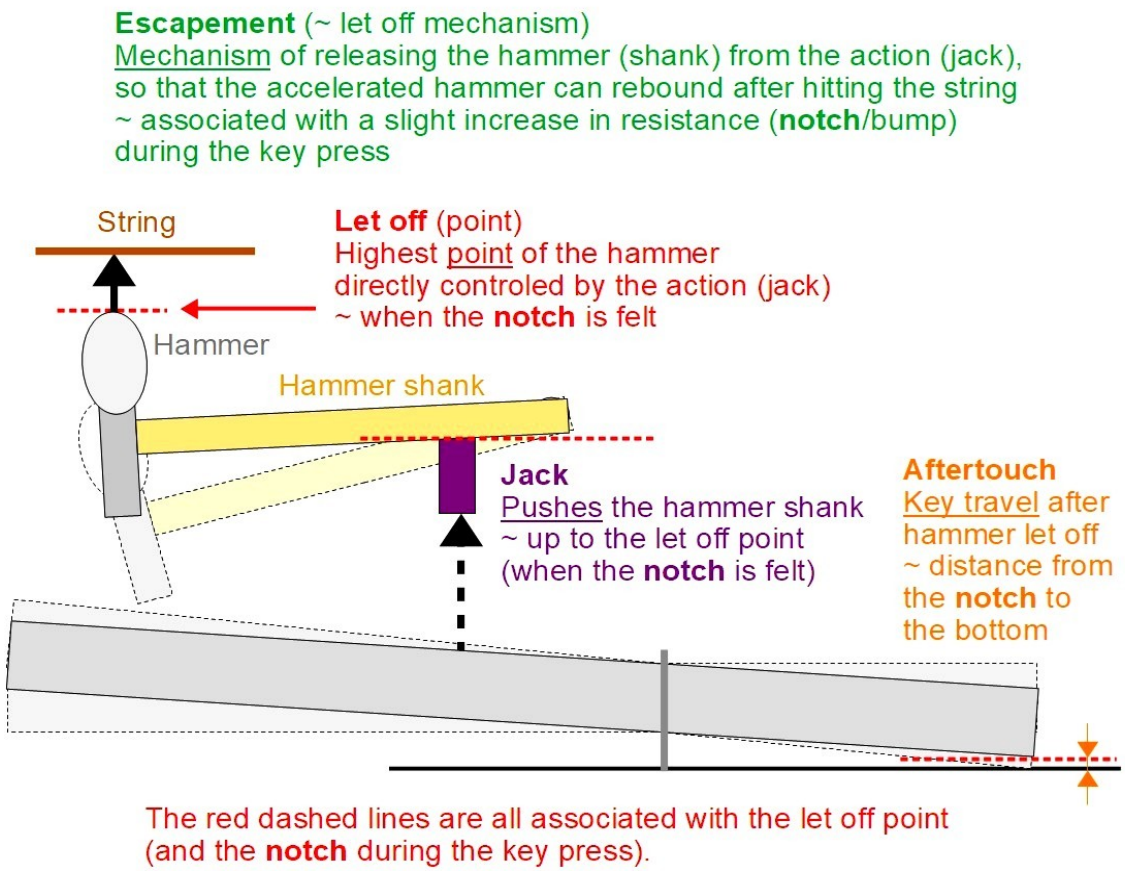
Strictly speaking, the maximum key travel at the front may be slightly different among models. If we need to be extra precise (e.g., for detailed comparison), the back key drop can be represented in terms of the percentage of the front key drop. For example, if the back key drop is 5 mm and the front key drop is 10 mm (typical), the value is 50%.

Touchpoint difference could affect the consistency of a key action much more than touchweight variations among different models (when just measured at front). In addition, if the back of the piano keyboard is extremely short, the touchpoint difference must be poor. Roberto thinks that this easy test must be one of the first things to do when comparing digital pianos.

#2: Direct Action Engagement Timing

One of the biggest challenges for Roberto on both of his pianos was how to play softly. It is certainly not as simple as depressing a key very softly. This may not at all produce a sound, on both of his pianos. This suggests that his digital piano must be simulating a grand piano reasonably well. However, there certainly is a difference. To find out, Roberto started to carefully observe his grand piano's key action. And at its core is grand pianos' ***escapement mechanism***.

Inside a grand piano, when a key is depressed, the action (more specifically, the jack) pushes the hammer (strictly speaking, the hammer shank) and disengages the damper. This process begins immediately after the key press. When the jack reaches a certain point (called *let off* point), the hammer (shank) is disengaged from the jack, strikes the string, and rebounds. This rebounding is necessary for the string to stay vibrating (thus sounding) until the damper returns (as the key returns to the original position). This can be seen in the following image.


Escapement (~ let off mechanism)
Mechanism of releasing the hammer (shank) from the action (jack),
so that the accelerated hammer can rebound after hitting the string
~ associated with a slight increase in resistance (**notch**/bump)
during the key press
String
Let off (point)
Highest point of the hammer
directly controled by the action (jack)
~ when the **notch** is felt
Hammer
Hammer shank
Jack
Pushes the hammer shank
~ up to the let off point
(when the **notch** is felt)
Aftertouch
Key travel after
hammer let off
~ distance from
the **notch** to
the bottom
The red dashed lines are all associated with the let off point
(and the **notch** during the key press).

Also, right around the let off point, the jack contacts a part called knuckle. And this process can be felt in the middle of the key press (typically at around 7 ~ 8 mm down from the original position) as a "bump" or "notch." After that, the key is totally disengaged from sound production. That is, only about the first 3/4 of key press is directly associated with the hammer movement and thus sound production.

While thinking about the mechanism, Roberto came up with the following analogy. The piano action is somewhat like throwing a ball to hit a gong (although the key action of an acoustic piano is guided and does not need to be as precise as the course of the thrown ball). That is, the player has control only up to the point of releasing the ball. When the ball hits the gong, the sound is made but how it sounds essentially depends on the control before the ball is released.

This situation contrasts with other keyboard instruments, such as organs and harpsichords. Organ keys are actually switches (electronic or mechanical). The player has *direct* control over whether or not the sound is being produced (but with no other control, e.g., loudness, by the press). Harpsichord keys push the jack and the "stick" on the jack plucks the string. The player has a more direct connection to the act (level) of plucking, just like guitarists and harpists.

The most common practice of simulating escapement (or let off) in (advanced) digital pianos is to implement the sensation of the notch mentioned above. However, Roberto does not think that this is so relevant. He thinks that the more important aspect would be how accurately a digital piano simulates the interaction of the key and the hammer of grand pianos. In particular, by the time the hammer hits the string, the key is already disengaged from the hammer (shank). As a result, the sound production in a grand piano must be considered as a sort of *indirect* process. Roberto thinks that *this* needs to be simulated.

Roberto also thinks that the understanding and mastering (mentally and physically) of this point must be helpful for being able to play softly. Now, playing softly does no longer appear to him as just depressing keys softly. It is the art of touching keys fast and strong enough for the hammer to move and reach the strings but gentle enough for the strings to make sounds at the intended level.

At this point, Roberto was convinced about the importance of the *initial* part of key press (prior to the let off point) for producing sounds and calls it ***direct action engagement timing***.

Limiting Test (Key Travel Limiting Test)

Roberto designed a test to estimate how much the early part of key press would affect the sound production. First, limit the maximum amount of key travel (e.g., by stacking coins in front of the key or even placing a finger tip, except for "waterfall" style keys) and identify whether any key press within this limit can produce a sound. If there is no sound, increase the limit and retry. Then, the minimal amount of the (early) key travel to produce sound is the result of this test, measured in mm. Or, it can be casually noted as "immediate" or "later" (in terms of timing). Although Roberto does this test casually, he also thinks that this test can be implemented with a hardware mechanism.

On Roberto's grand piano (and on other grand pianos he tried in stores), the result of the Limiting Test is less than 2 mm, i.e., basically "immediate." On his digital piano, it is about 5 mm (about half way to the key bottom), i.e., slightly "later," but there are other models which are much "later" in this respect. For example, on some models, there would be no sound until keys hit the bottom. The difference can certainly be felt when he compares multiple pianos side by side.

Now, Roberto thinks that this is an extremely important point, which is rarely discussed in reviews of digital pianos. The key touch of a digital piano must be closer to that of a grand piano if the digital piano simulates this property appropriately. And the ability to play softly must depend on the initial part of each key press. For example, in order to provide minimally sufficient speed and force at the beginning of a key press, Roberto tries to place fingers at the surface of a key (i.e., not much higher

up from the key surface). This way, he thinks he can control the sound production more flexibly.

#3: Inertia

As for Roberto's digital piano, it is fairly good in terms of the two properties discussed so far: touchpoint difference and direct action engagement timing. Nevertheless, Roberto still feels that there is a big difference in key touch between his two pianos. He feels this especially when he needs to depress a single key repeatedly or play fast across multiple keys.

In these situations, that is when playing fast, the keys on his grand piano seem to rebound more actively than his digital piano. As a result, in spite of little static touchweight difference between his two pianos, the keys on his grand feel somehow "heavier."

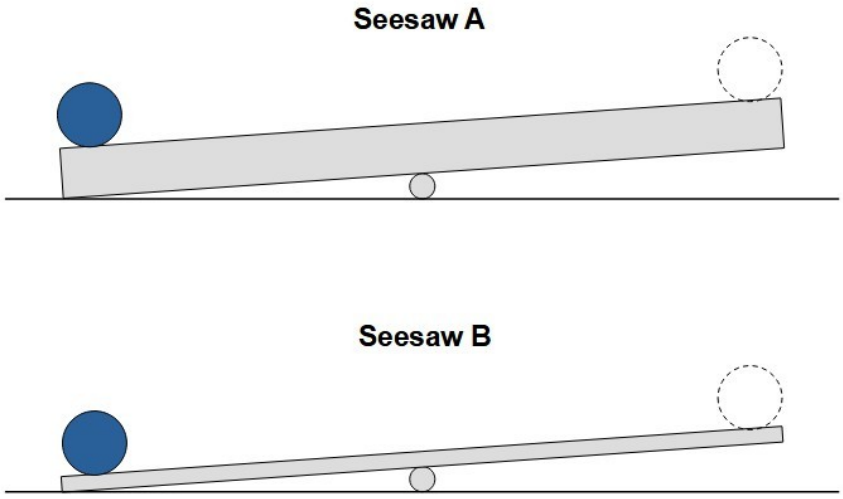
To find out why, Roberto continued to experiment. First, when he was tapping keys very lightly (without making sound), he noticed that the keys on his grand piano are noticeably slower to rebound than those on his digital piano. This happens in just a fraction of a second and it did not seem to be something that can be easily measured. Nevertheless, the difference seemed crucial. He thought it must be associated with ***inertia***, the dynamic aspect of key touch.

Technically speaking, inertia is the resistance of mass to change state/speed (i.e., acceleration and/or deceleration). That is, a heavier object resists to the change in speed more than a lighter one. For example, bass keys of a grand piano is heavier (to be able to strike heavier strings) than treble keys and thus slower to move; but heavier bass strings keep moving longer once started; as a result, bass notes can be sustained longer. The reason why some treble keys have no dampers is that they cannot sustain sound as much and do not really need dampers for the first place.

Now, while static touchweight is about balancing and breaking the balance, inertia is about resistance to change, i.e., about moving. Thus, even though Roberto's digital and grand pianos have about the same amount of static touchweight, the keys on grand piano must have greater inertia.

One might think that a greater inertia would be hindrance to faster key movement. This is not so. The increased force of a rebounding key is actually helpful for swiftly generate the next note.

In this connection, Roberto imagined two seesaws, one is heavier than the other. In both cases, two objects with the same weight can balance the seesaw. But the heavier one would move (or come to stop) more slowly. This must be what is happening with the keys. Here is a relevant image.



Eventually, Roberto came up with a way to quantify the difference. The starting point was to repeatedly tap a key. If the rate of tapping increases, the subsequent taps will occur before the key returns to the original position. Then, he feels the force from the rebounding key. Roberto actually felt the increased force when the repetition rate increased to a certain point. This experience led to the following test.

Tapping Test (Key Tapping Test)

This test is to estimate piano key inertia by repeatedly tapping a key lightly without making sound (with only a few millimeters of key travel), starting slowly, then gradually increasing the rate. The inertia must be related to the rate of tapping when the finger feels the increased force of the rebounding key *every time* the key is tapped. The result can be measured in terms of BPM, using a metronome. Or, it can be measured in terms of taps per second, using a loudly ticking clock/watch. It can also be casually noted as "large" or "small" (inertia). Naturally, a key with larger inertia must have a slower rate of repetition to have increased resistance. So, this test should be done on both bass and treble keys because heavier bass keys have larger inertia.

Note that this test involves a subjective element of "feeling" increased force. So, strictly speaking, it is not completely objective (yet). However, this force detection part is binary, i.e., yes/no, and could still be mechanized, e.g., by creating a special equipment. So, with this potential, we may still consider this test reasonably objective.

On his grand pianos, the result of the Tapping Test is about 300 ~ 360 BPM (5 to 6 taps per second), larger inertia on bass and smaller on treble keys. According to casual tests of other grand pianos in stores, the results were similar. On his digital piano, it is *at least* 480 BPM (8 taps per second) even on bass, which was the fastest Roberto could tap. Then, on his portable keyboard, he never really felt the force of a rebounding key; there is virtually no inertia and it felt "wimpy."

Now, Roberto felt that he nailed down something important. First, static touchweight is relevant only when keys are stationary. But in order to produce sound on a grand piano, keys must be depressed sufficiently fast (recall the discussion in the previous section on the escape mechanism), even for playing softly. Then, to move a stationary object, inertia must be involved. And when in use, the piano action is constantly on the move. So, it must be inertia that be more relevant *all the time*. And especially when playing fast, the fingers must be feeling a substantial force from rebounding keys due to inertia.

In the end, Roberto came to think that his perception of keys being "light" or "heavy" is more to do with inertia (dynamic touchweight) than static touchweight. Roberto thought that this point has rarely been clarified or emphasized in online reviews and comments.

Now, in order to increase inertia, some, more advance digital pianos intentionally increase the weight of their keys. His digital piano does not seem to be sufficient in this regard. So, he came to a conclusion that smaller inertia is the most lacking part of his digital piano.

#4: Friction

There are certain models of digital piano which are said to cause more fatigue. Roberto tried such a model in comparison to another one, side by side in a piano store. He too had a sense but it was not so clear. Roberto thought: if the fatigue level is higher on some digital pianos, it should be more noticeable, say, after extraneous playing, e.g., loudly, fast, and involving a lot of chords.

In order to simulate playing a chord with many notes, Roberto used a pen and pressed most of the white keys in an octave. This would effectively multiply whatever the property involved in the process, in comparison to depressing just a single key. He did this on the suspected model and another model right next to it. He tried different ways of doing this. Then, eventually, he had a hunch about a possible source of fatigue.

First, Roberto checked that the static touchweight is about the same on both models. So, it required about the same amount of force to the keys to go down. Next, he tried to do this very slowly so that inertia is not involved.

Then, after the keys under the pen started to move down, Roberto continued to move the keys down and up repetitively, but very slowly. By doing this, he noticed the difference between the two models. The suspected model requires more force to move down and up the keys under the pen. He thought that the relevant property must be ***friction***, which should be caused by continuous resistance from rubbing the contact surface within the digital piano key mechanism. This led to the following test.

Pen Test (Slow Up/Down Pen Test)

This test should be done on two digital pianos side by side. First, place a pen (or something analogous) on seven (or so) of white keys. Very slowly press the entire pen down to the key bed without producing sound. Then, move the pen up and down repeatedly very slowly so that there still is no sound (if there is escapement simulation, avoid the involved area).

The resistance to slowly moving the keys up/down must be associated with the friction involved in the key action. If we compare two digital pianos, we can describe any difference as either “more” or “less” resistance to slow key movement. Although Roberto did this test casually, he thinks that this test too can be formalized with some sort of force sensors.

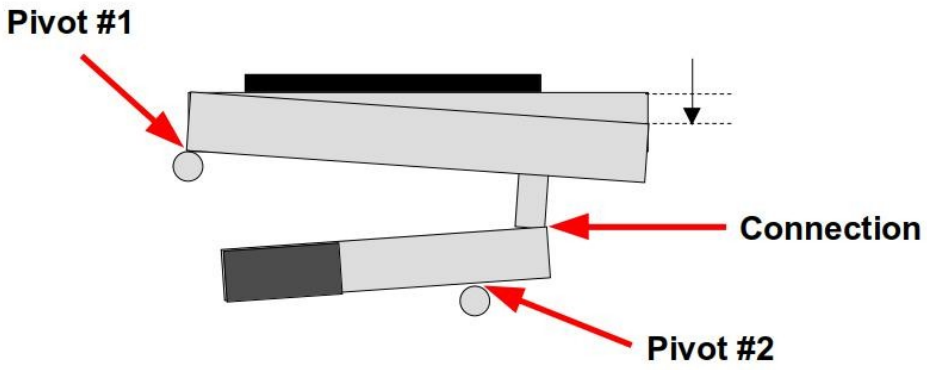
Now, comparison of the suspected model and a grand piano was revealing. The suspected model had more resistance to slow key movement than the grand piano. As for Roberto’s digital piano, the test result is not that different from his grand piano.

Although Roberto does not know exactly, he has a speculation about why digital pianos could have higher friction than grand pianos. First, grand pianos contains a very complex action which engages with the hammer. However, the action does not seem to involve a lot of friction as Roberto was able to check with the Pen Test.

Then certain models of digital piano seem to have more sources of friction. One typical difference between grand pianos and most digital pianos (with some sort of weighted hammer mechanism) is the structure of the key.

While grand pianos have seesaw keys (balance pin at the middle), most digital pianos employ folded keys to save space. In addition to the key segment with touch surface, there is another segment to simulate the hammer action. This latter segment has some sort of weight to balance the front segment, commonly placed below the touch key.

Then, folded keys of a digital piano have two pivots, one for the touch key segment and another for hammer-simulation segment as shown in the following image.



So, simply put, digital pianos have twice as many pivots as bases of key movement, as well as the connection part. If the friction involved in these pivots are significant, it might cause more friction.

In addition, the two key segments of digital pianos must be connected in some way. This could cause additional friction, possibly more than a grand piano key action.

Notion of "Heaviness"

Although piano key action is discussed in terms of "heaviness," Roberto thinks that this term is overloaded and ambiguous. To him, it could mean at least three different properties. That is, key "heaviness" may be the result of any combination of the following three properties:

- **Static touchweight**: This is about breaking the *balance* involving a key. This is most relevant at the beginning of key depress. Since even a grand piano has about 100% difference in static touchweight between the front and the back of a key, even this much of difference does not seem to be critical. However, this static touchweight can be enormously large (say, 400%) at the back of a digital piano key. Naturally, this much is certainly noticeable and can affect the playability.

- **Inertia**: This is about resistant to *change* and thus dynamic in nature. Since heavy objects have higher inertia, heavier keys feel more resistance to move. Even on the same piano, bass keys exhibit more resistance to move than treble keys. When playing, this property should be felt as rebounding force. And an

appropriate amount of inertia actually helps playing fast by assisting fast/repetitive key press.

- **Friction**: This is about resistance from *rubbing* during surface contact. The amount of friction involved in a piano key is very small. Thus, it is rather difficult to detect the difference among different pianos. However, extraneous playing may still be felt by the player and can cause fatigue.

Roberto's Digital Piano

After his exploration, Roberto realized that his digital piano is a quite decent intermediate model for the price. Even though the static touchweight is lighter on black keys, this turned out to be largely irrelevant to him. As for its touchpoint difference, it is one of the best among digital pianos.

Its direct action engagement timing is quite decent as well, although not exactly like a grand piano. There are many digital pianos much worse than this. On some digital pianos, sounds can only be produced near the bottom of each key. This is far from grand pianos and the key touch must be different.

The weakest point of his digital piano is inertia. The keys do not rebound as much as grand pianos. So, when Roberto uses his digital piano, he needs to be aware of the difference in inertia between his two pianos. In a sense, since it is more challenging to play a fast passage or repeat a note fast on his digital piano, he usually have easier time on his grand piano.

Roberto's digital piano does not have excessive friction. So, he does not need to be worried about it. If practice on his digital piano requires effort, it is pretty much the same amount of effort required on his grand piano.

Roberto's digital piano is aging. Over time, its key surface became uneven. Certain keys make more and more sound/noise. So, he will eventually replace it with most likely a better one especially with respect to inertia. This would happen if his current digital piano can no longer function or he moves to an apartment.

Conclusion

In this document, we discuss Roberto's experience with his digital piano focusing on its sound and key action. As for sound, since he uses his digital piano usually with

headphones, it is essential that he choose decent headphones. When he uses external speakers, he needs to use a graphic equalizer to compensate various factors involved in the specific condition of sound generation in his room. This adjustment actually improves the quality of his audio system for listening to music as well.

As for key action, Roberto identifies four properties to consider. Touchpoint difference is a crucial element for key touch consistency, esp. key back playability. It must be considered as a prerequisite for a digital piano key action in comparison to a grand piano action. Direct action engagement timing is important for soft playing. It would be hard to transfer skills between pianos if they differ greatly with respect to this property. Inertia appears to be relevant to repetition and fast playing. A digital piano key action with smaller inertia may not be able to simulate the behavior of grand piano's rebounding keys, especially when playing fast. Friction is resistant to key movement. If friction is excessive, the player may feel fatigue more easily.

In addition, these properties can interact with one another in a complex manner. For example, Roberto always felt difficult to play fast *and* softly. And there is a good reason. While fast playing requires speed to deal with inertia, soft playing requires very fine control at the beginning of key press (with respect to direct action engagement timing). This certainly requires practice.

Then, for each property, Roberto identifies an associated objective test method. The Slope Test simply measures how much the back of a fully depressed white key goes down. The result is proportional to the pivot length, the decisive factor for touchpoint difference. The Limiting Test measures the minimal key travel to produce sounds. The result is relevant to how "immediately" the key responds to touch. The Tapping Test measures the rate of key rebounding, which is associated with inertia and the amount of force involved in movement. The Pen Test measures friction by effectively multiplying the value associated with a single key by depressing multiple keys at the same time.

These tests could provide quantified results, e.g., by implementing hardware mechanisms. However, as Roberto becomes familiar with the tests, he can now quickly estimate the outcome by casually doing these tests. This ability was quite useful when he visited local piano stores to compare multiple models.

Roberto's endeavor certainly helps him to transfer skills between his two pianos. For example, to play softly, he places his fingers right at the surface of a key and pays utmost attention to the beginning of each key press. Even on his digital piano, just imaging the hammer starts to move seems helpful. He tries to use minimally sufficient force for the hammer to reach the string.

When Roberto plays bass chords softly, he would use his arm to coordinate all the notes and also apply an appropriate amount of force at the right speed. When Roberto repeats a note or tries to play fast on his digital piano, he can still imagine greater inertia on his grand piano.

Finally, we hope that this document be useful for other people as well. Especially with the objective test methods, we could share and compare the results openly. In a sense, the information in this document can be considered “open source.” It can be jointly improved by the community, e.g., with respect to the (choice of) properties and test methods.